STAN Tool

Systematic Large Signal Stability Analysis technique for multi-transistor RF Circuit

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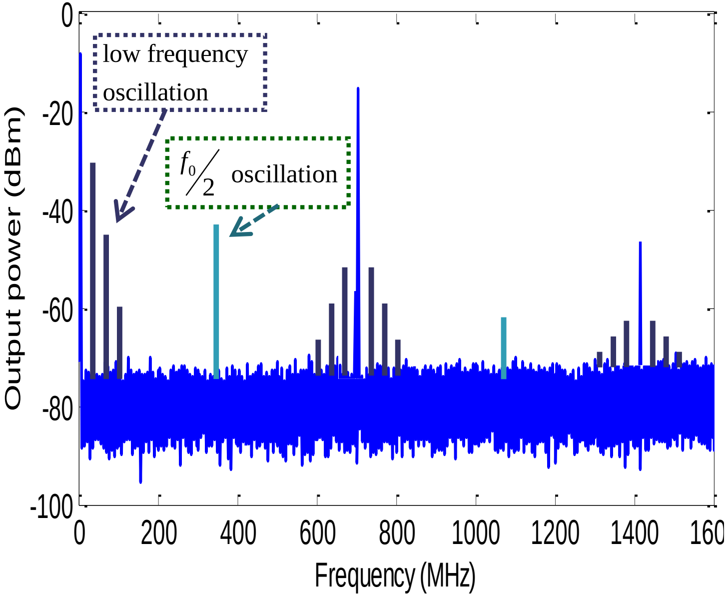
Oscillations in RF Power Amplifiers

RF Power Amplifiers are prone to (unwanted!) oscillations



Typical ones:

- low-frequency oscillations, often linked to bias networks, can be detected using small-signal simulations

- parametric oscillations function of the input drive signal, have to be detected in large signal

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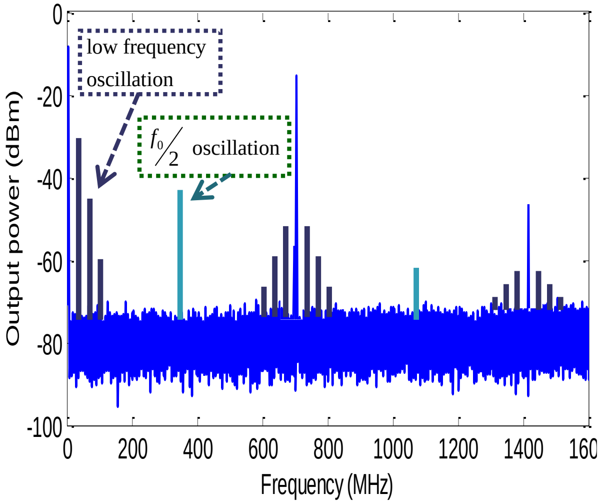
Existing Methods



Linear analysis "small signal"

- K factor
- Normalized Determinant Function (NDF)
- Stability envelope

Non-linear analysis "large signal"

- Nyquist criterion
- NDF
- Bolcato, Di Paolo & Leuzzi, Mochizuki, …

Either not complete or too complex !!!

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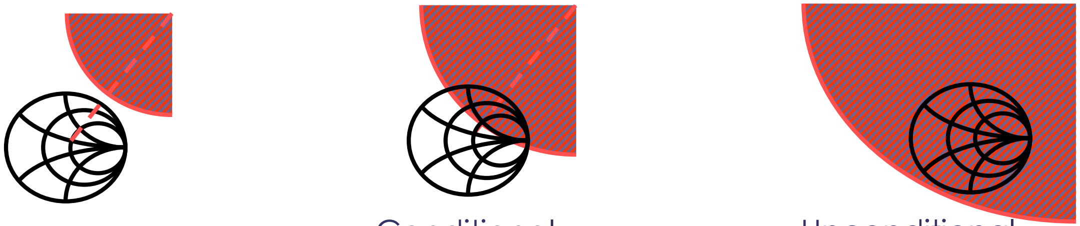
Existing Methods

Linear analysis

Widely used: K factor (also μ and μ’ now)

- $K>1$ & $|\Delta| <1$: unconditional stability of two port network
- $K<1$: conditional stability → stability circles



Unconditional stability

Conditional stability

Unconditional instability

Limitations:

Only indicates that a stable circuit will continue to be stable when loading it with passive external loads at the input or output

Do not guarantee the internal stability of the circuit !

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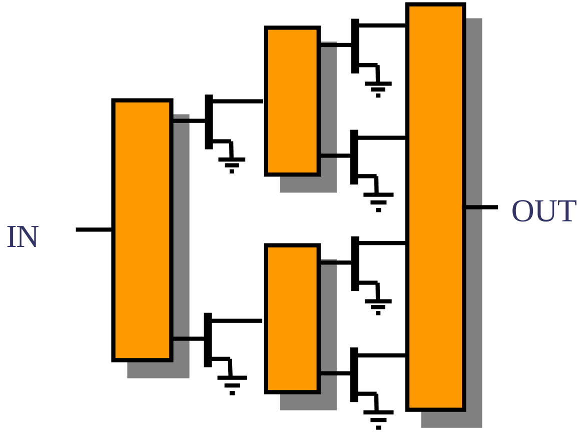
Existing Methods

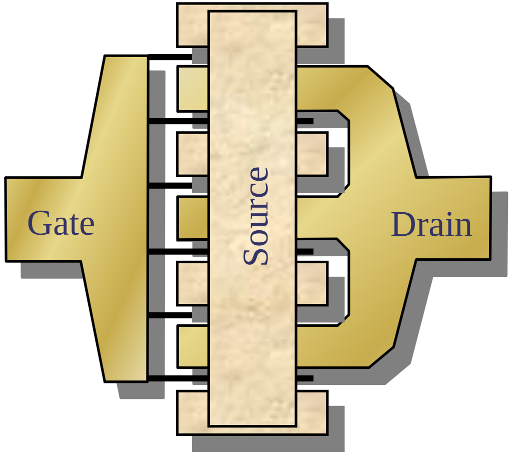
Linear analysis

Potentially instable architectures for which <u>K factor is not enough</u> (-> see Application Note)

<u>Multi-stage power amplifier</u>



<u>Multi-fingers transistor</u>



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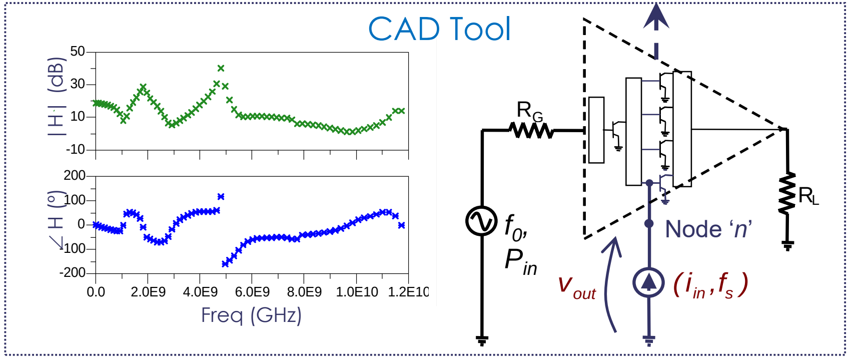
Pole-Zero Identification

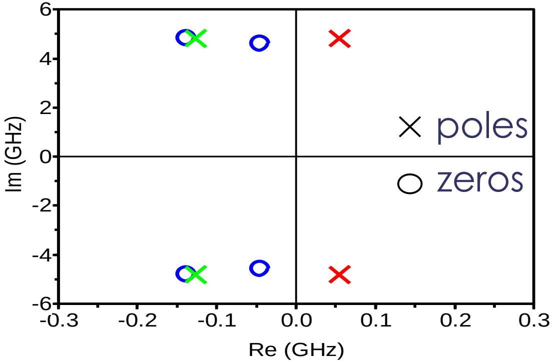


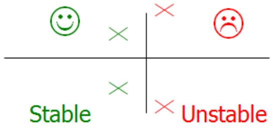
$H(j\omega)$

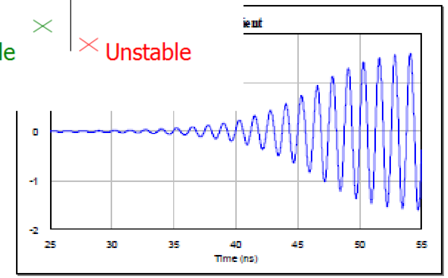
Frequency domain identification techniques

$$\hat{H}(s) = \frac{\prod_{i=1}^{n}(s - z_i)}{\prod_{j=1}^{p}(s - \lambda_j)}$$

Pole-zero plot







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Key Elements

- Suitable for both linear and non-linear stability analysis
- Very easy to use
- Very easy to analyze results
- Notion of “stability margin”
- Oscillation mode knowledge -> Help to find the suitable stabilization strategy
- Parametric Analysis implemented
- Monte-Carlo Analysis

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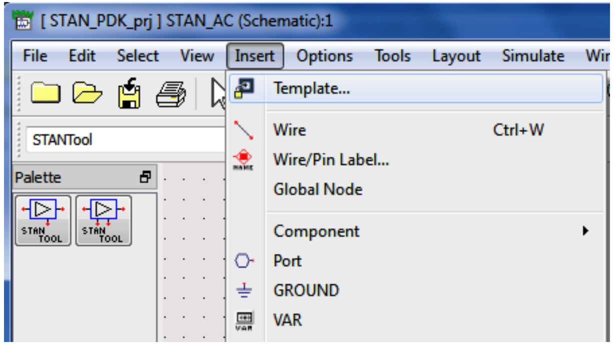
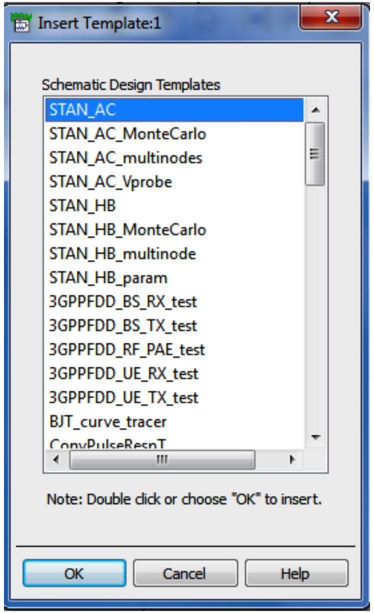
Combining STAN with CAD tools

Keysight ADS

Design Kit of Templates is available





- AC simulation for small-signal stability analysis
- HB simulation (mixer-mode) for large-signal stability analysis

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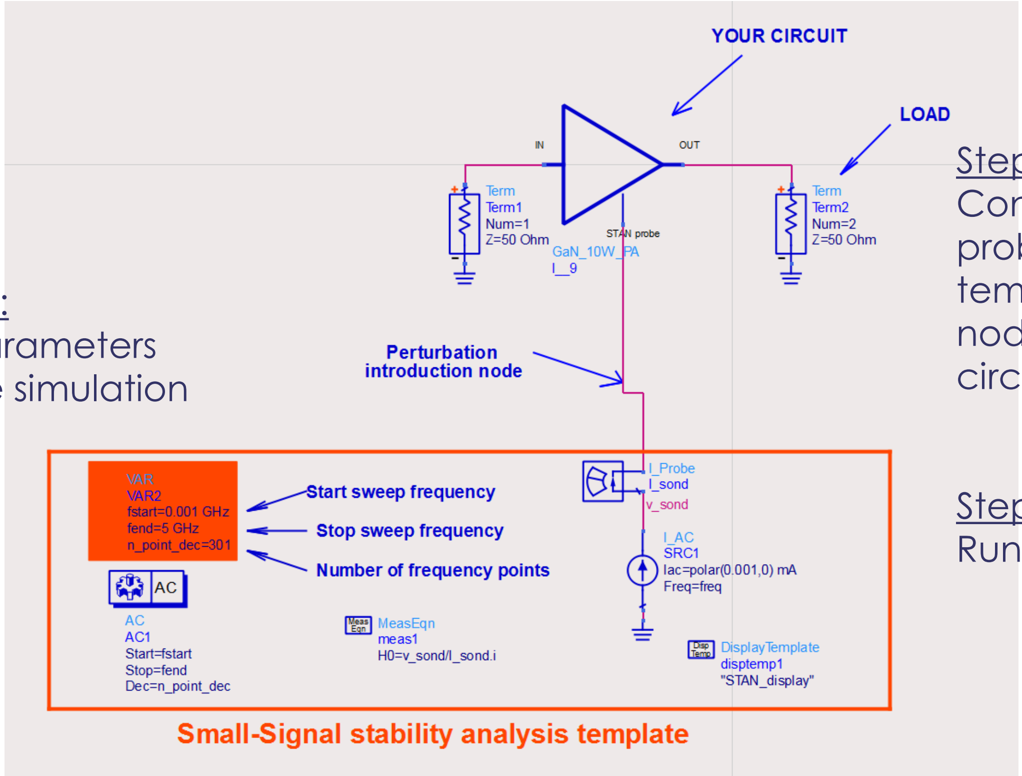
Keysight ADS



Step 2:
Set parameters for the simulation

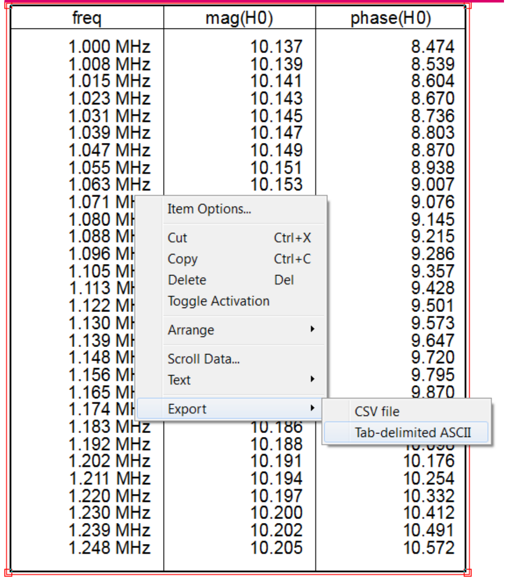
Step 1:
Connect the probe from the template to a node of your circuit

Step 3:
Run simulation

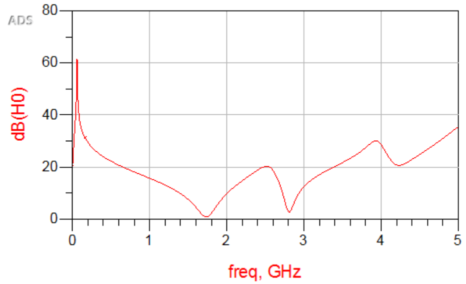
Keysight ADS

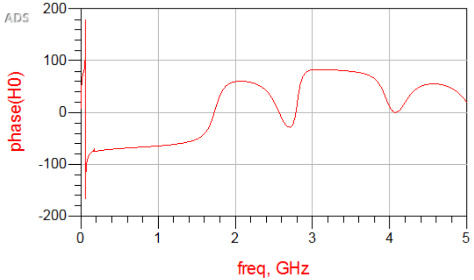
Step 4:

- results are displayed in ADS
- Export the results in a text file



freq	mag(H0)	phase(H0)
1.000 MHz	10.137	8.474
1.008 MHz	10.139	8.539
1.015 MHz	10.141	8.604
1.023 MHz	10.143	8.670
1.031 MHz	10.145	8.736
1.039 MHz	10.147	8.803
1.047 MHz	10.149	8.870
1.055 MHz	10.151	8.938
1.063 MHz	10.153	9.007
1.071 MH		9.076
1.080 MH		9.145
1.088 MH		9.215
1.096 MH		9.286
1.105 MH		9.357
1.113 MH		9.428
1.122 MH		9.501
1.130 MH		9.573
1.139 MH		9.647
1.148 MH		9.720
1.156 MH		9.795
1.165 MH		9.870
1.174 MH		
1.183 MHz	10.186	
1.192 MHz	10.188	
1.202 MHz	10.191	10.176
1.211 MHz	10.194	10.254
1.220 MHz	10.197	10.332
1.230 MHz	10.200	10.412
1.239 MHz	10.202	10.491
1.248 MHz	10.205	10.572





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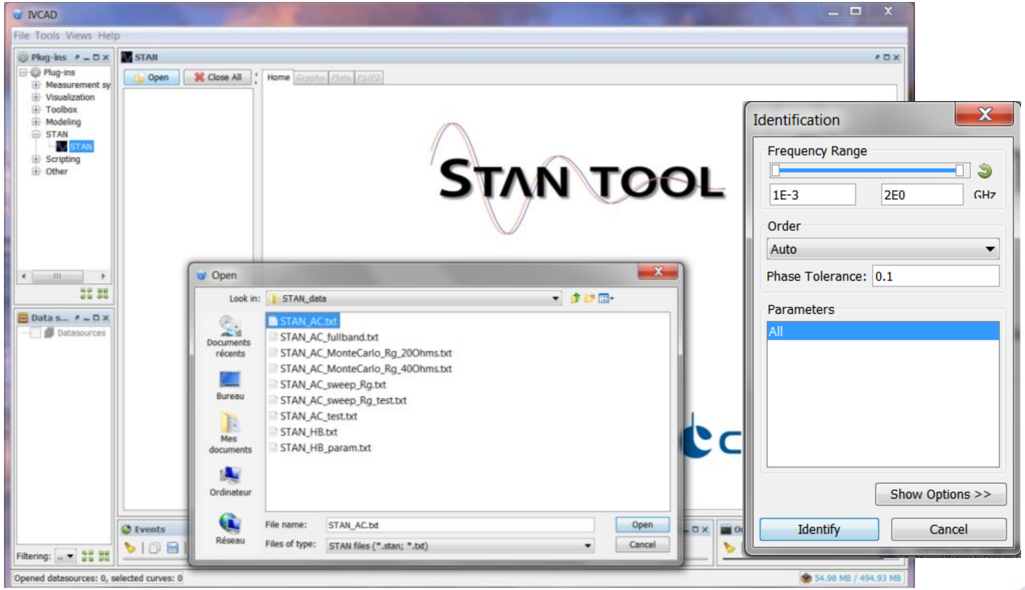
Combining STAN with CAD tools

Keysight ADS

<u>Step 5:</u>

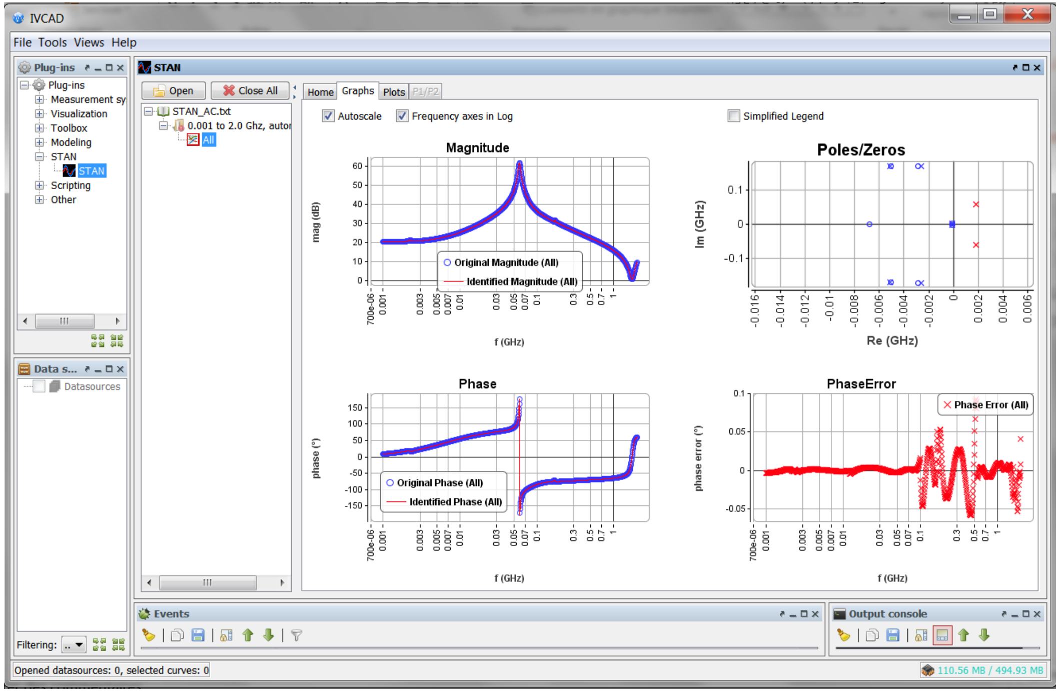
- Open the file in STAN tool and launch the identification



Combining STAN with CAD tools

Keysight ADS

Step 6:
- Check the results



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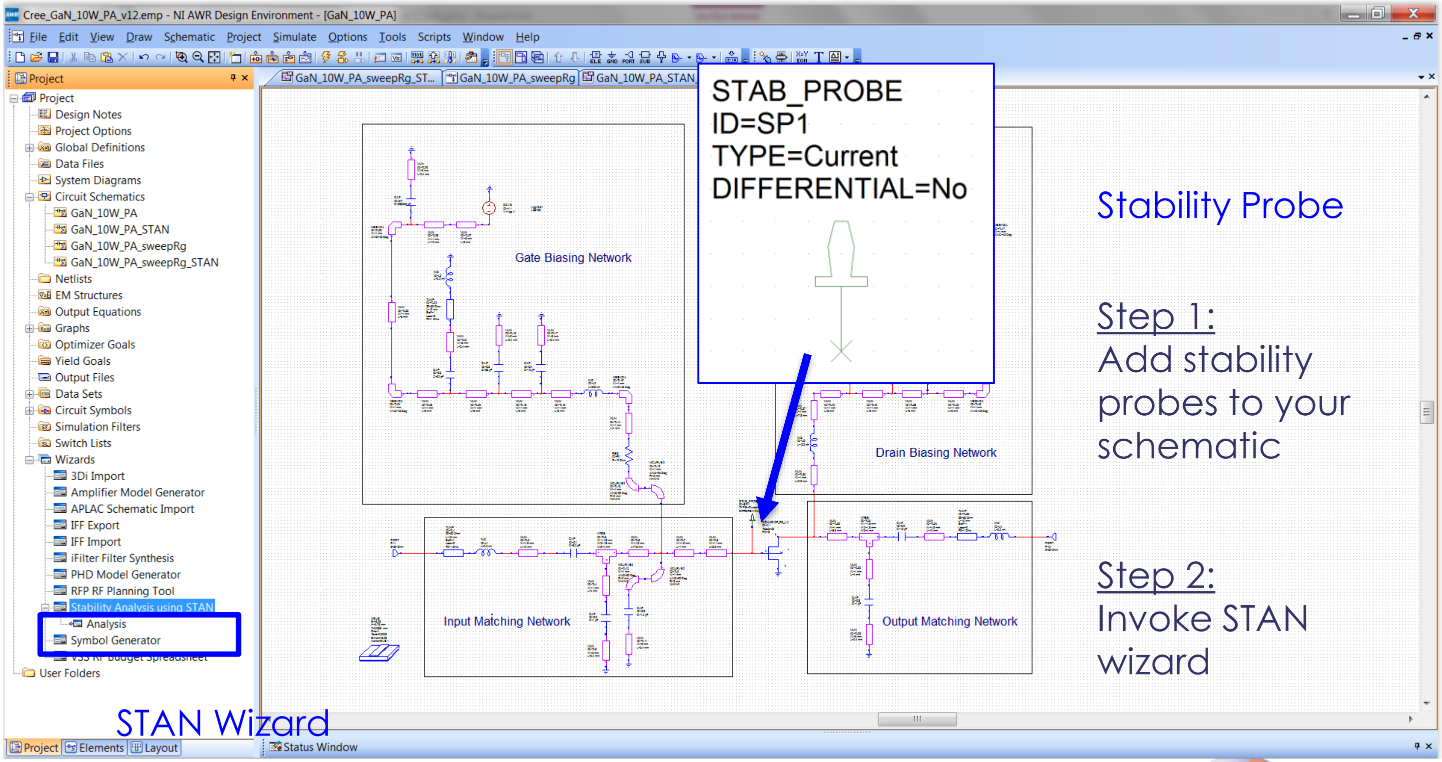
Combining STAN with CAD tools

NI AWR Microwave Office

Integrated STAN Wizard in MWO v12



Stability Probe

Step 1:
Add stability probes to your schematic

Step 2:
Invoke STAN wizard

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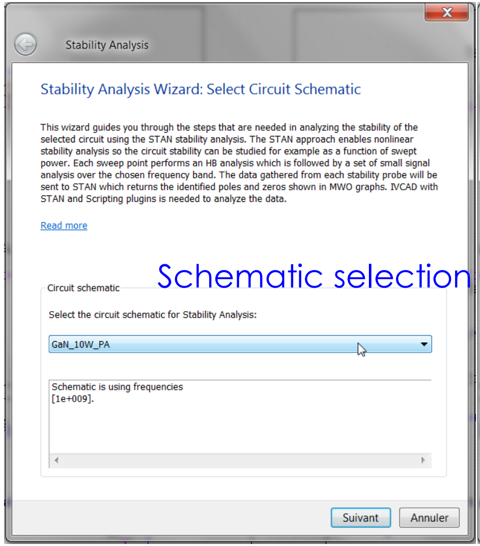
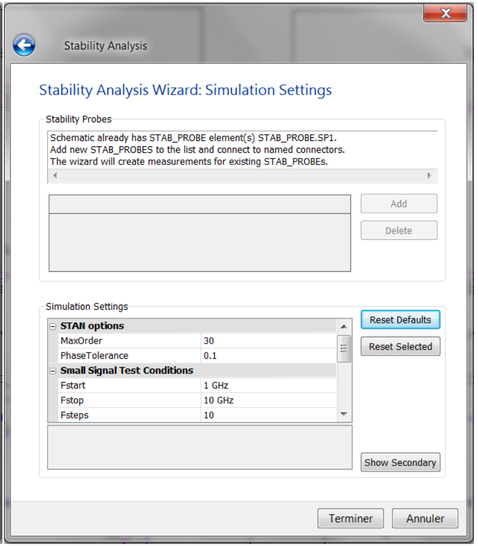


Schematic selection



Step 3:

Within STAN wizard
- Set the parameters for the stability analysis
- Launch the analysis

Node(s) selection

STAN settings

Frequency range

Drive conditions (small signal / large signal)

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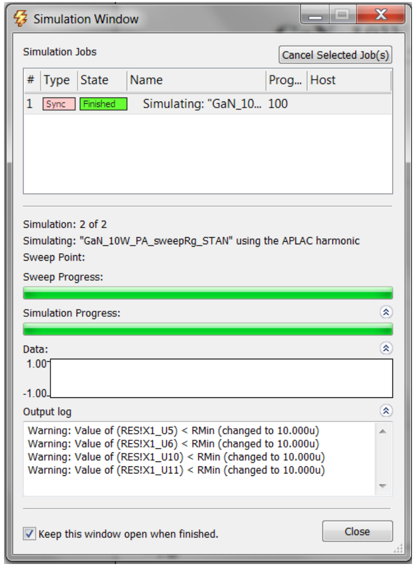
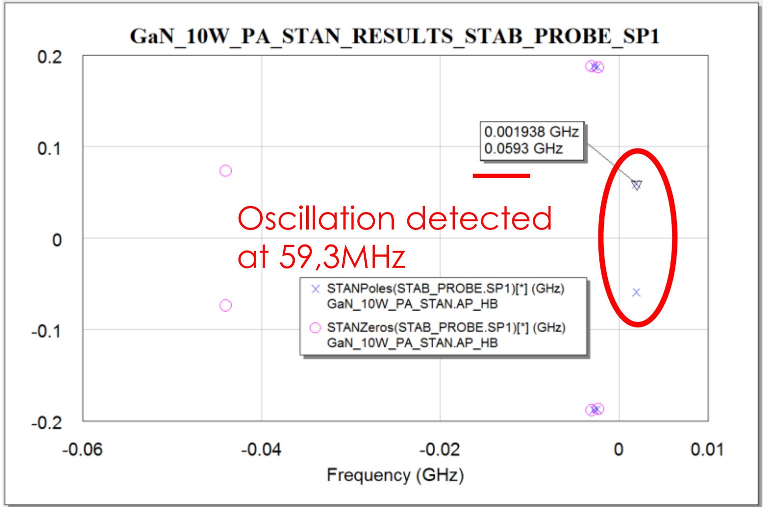


Step 4:

- Aplac simulation is run – results are automatically sent to STAN. STAN processes the data and sends results back to MWO
- Check the pole/ zero map results



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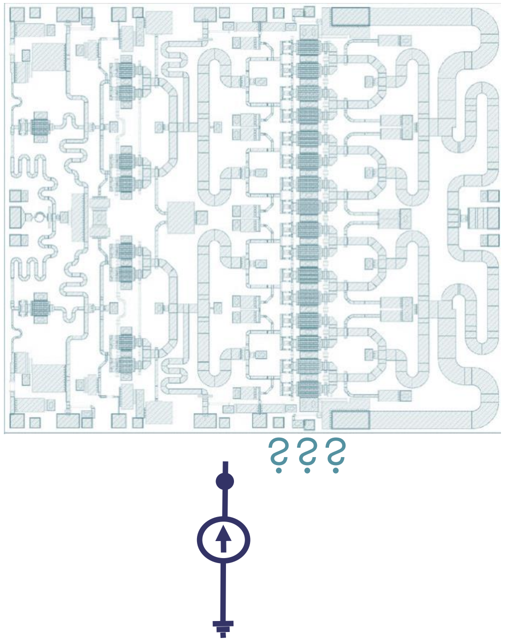
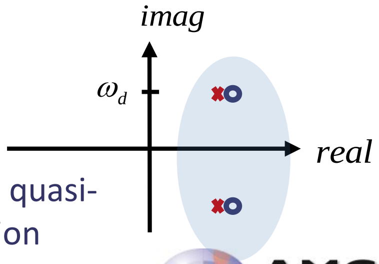
Selecting the Node

Where to connect the probe for STAN analysis ?



SISO transfer function → exact pole/zero cancellations are possible

Pole/zero cancellations are associated with the lack of *controllability* and/ or *observability* in the system



Pole-zero quasi-cancellation

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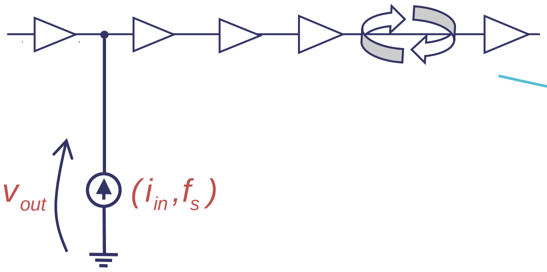
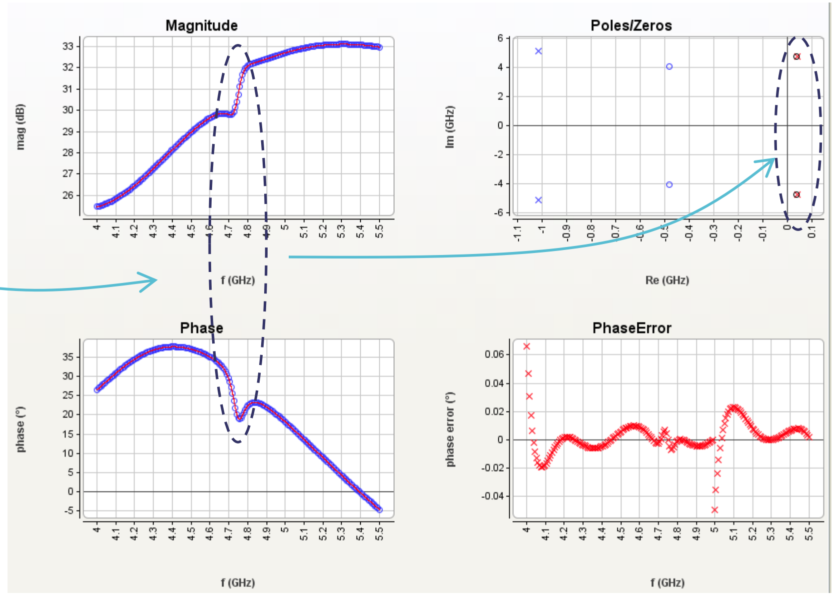
Physical quasi-cancellations

When part of the circuit dynamics is electrically isolated from the node selected for the analysis, poles representing this dynamics appear quasi-cancelled by zeroes and the effect of this dynamics on the transfer function is very slight





this node has very low sensitivity to that dynamics (low degree of observability and/or controllability)

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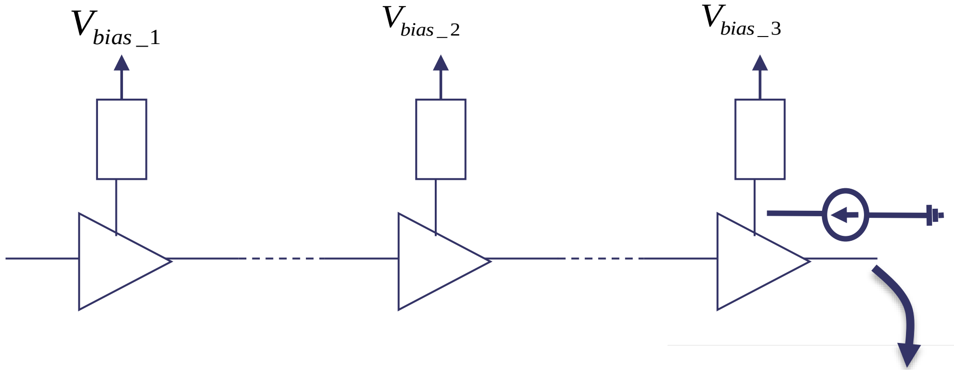
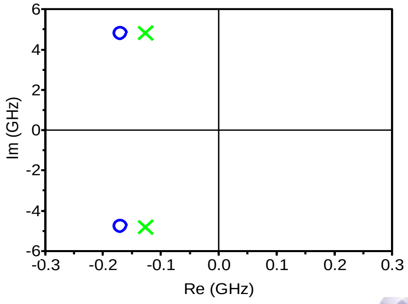
In multistage Circuits

Example of a three-stage PA exhibiting an oscillation



Connecting the probe to a node of the 3rd stage, no instability is detected (we are electrically isolated from where the actual oscillation takes place).



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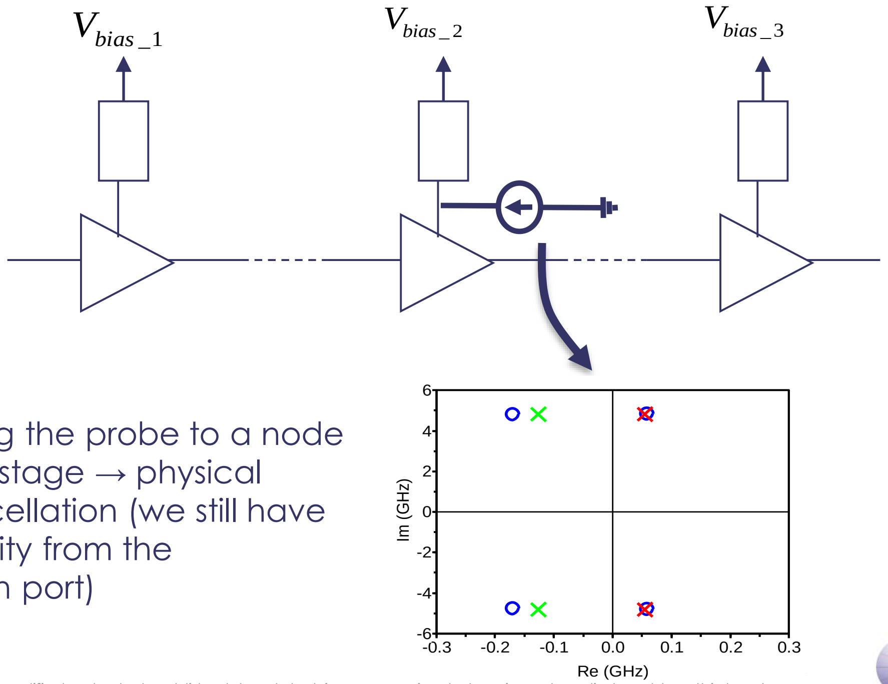
In multistage Circuits

Example of a three-stage PA exhibiting an oscillation



Connecting the probe to a node of the 2nd stage → physical quasi-cancellation (we still have low sensitivity from the observation port)

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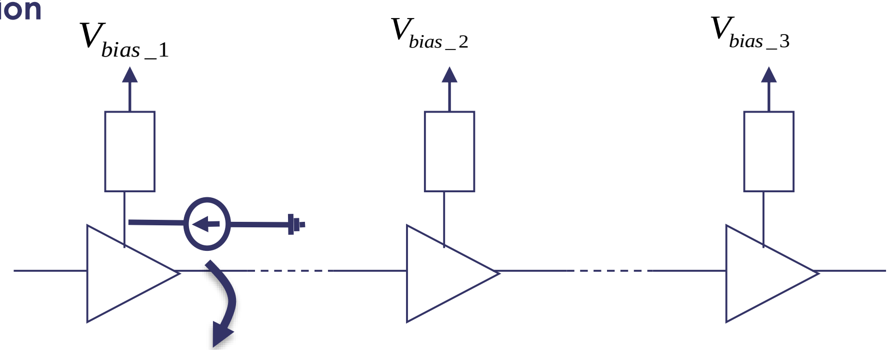
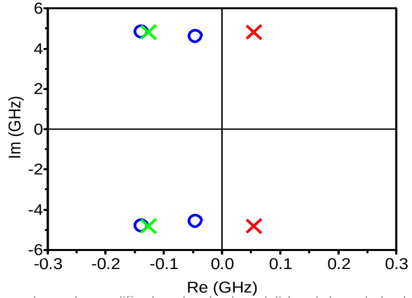
In multistage Circuits

Example of a three-stage PA exhibiting an oscillation





Connecting the probe to a node of the 1st stage → The oscillation is clearly detected, unstable poles are not quasi-cancelled with nearby zeros (high sensitivity). We can conclude that the origin of the oscillation is located in the 1st stage

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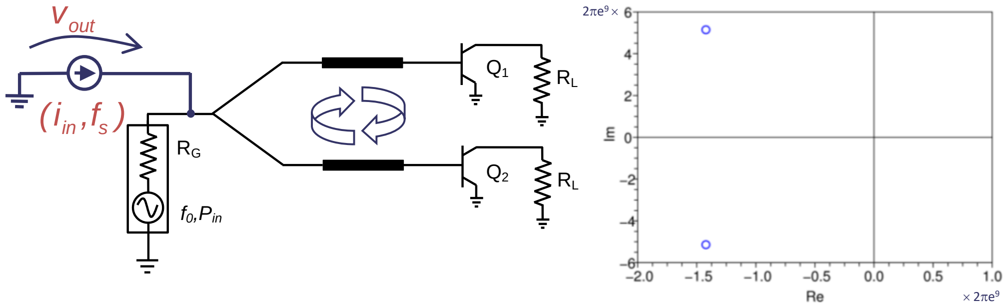
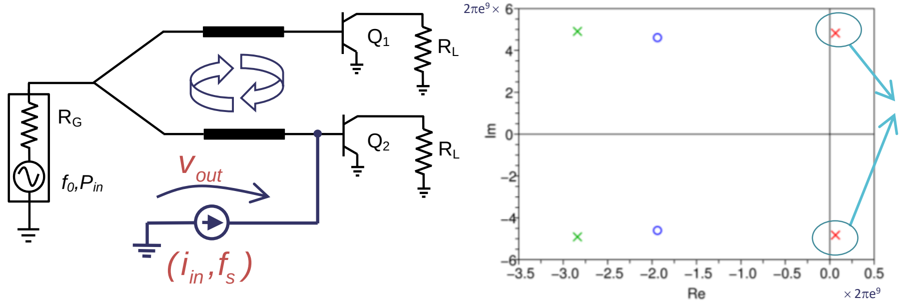
Odd mode oscillation in combined amplifiers

Oscillation at $f_0/2$ is very common in amplifiers with parallel power combining structures



Odd mode oscillation is not detected at the combining node. Exact pole-zero cancellation



Odd mode oscillation is clearly detected at the gate of the transistors

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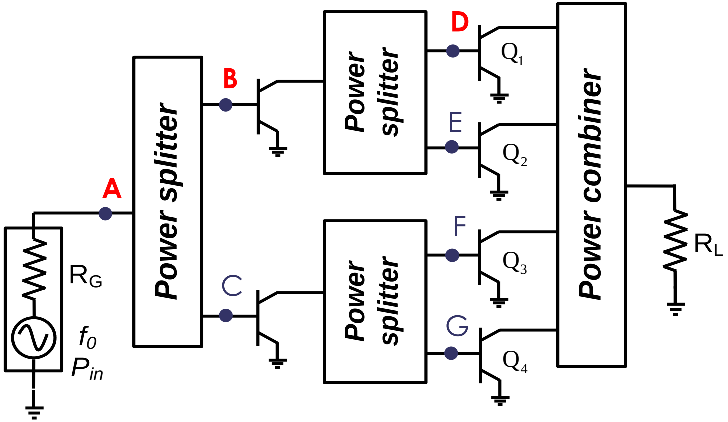
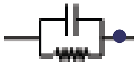
Odd mode oscillation in combined amplifiers



1st step: analysis in nodes A, B and D

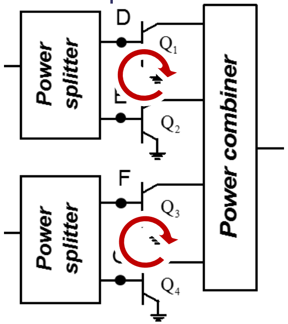
A	B	D	Oscillation type	Preferred strategy
X	X	X	Even mode	 B,C or/ and D, E, F, G
-	X	-	Odd mode in 1st stage	 B C
-	-	X	Odd mode in 2nd stage	See next slide
-	-	-	No oscillation	-

Stabilization networks can be optimized using parametric analysis -> find the **best trade-off between stability and RF performances**

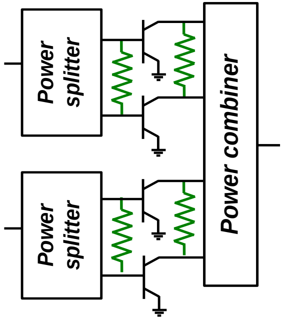
STAN Tool

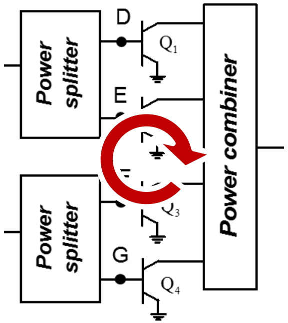
Odd mode oscillation in combined amplifiers

Test of the 4 branches with 4 probes, changing the phase

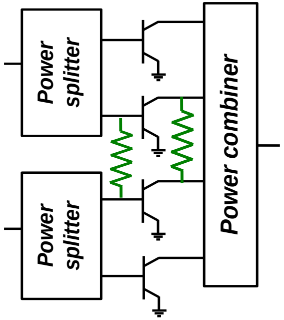


Odd mode oscillation
[+ - - +] or [+ - + -]
→ Q_1 oscillates out of phase with Q_2, same for Q_3 and Q_4





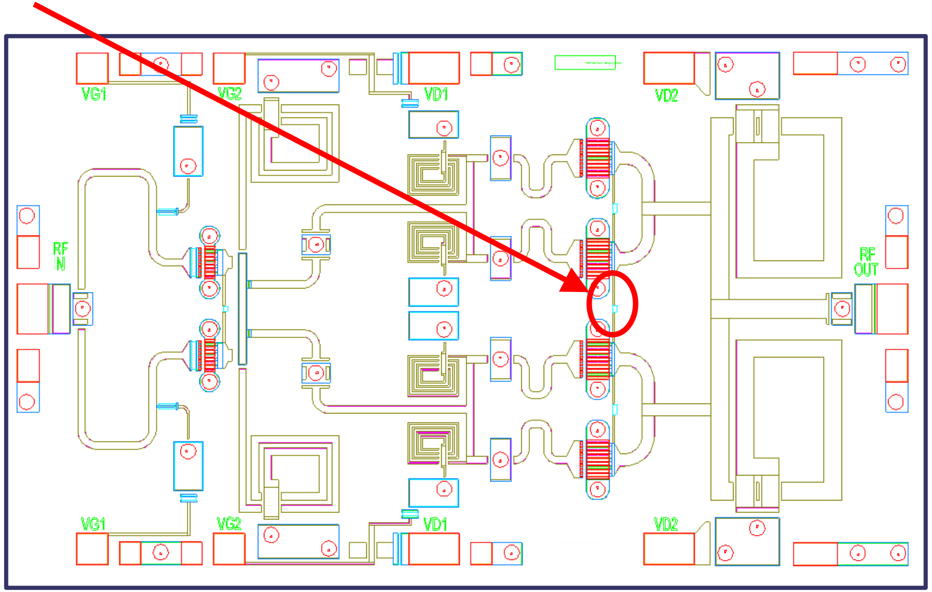
Odd mode oscillation
[+ + - -]
→ Q_1 and Q_2 oscillates out of phase with Q_3 and Q_4



X-band class-E PA

X-band MMIC class-E PA – 0,15µm GaN process

When tested in the lab with RF signal, increasing the input power makes the middle output interbranch resistance to blow up



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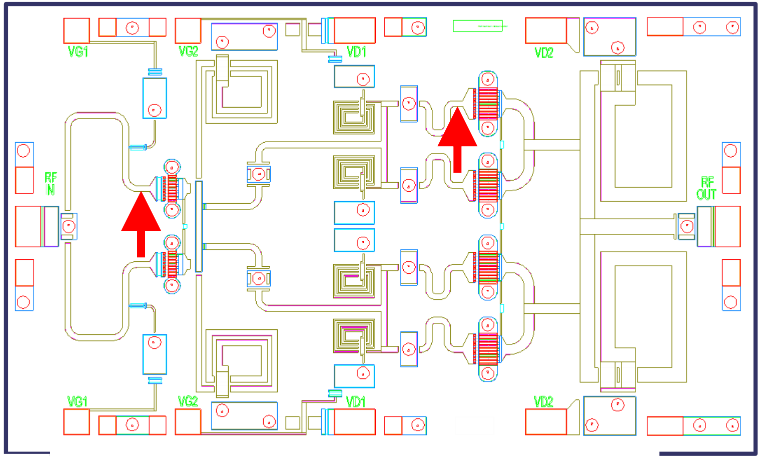
X-band class-E PA

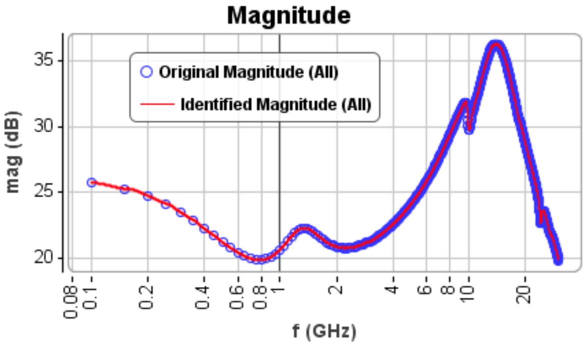
DC stability analysis

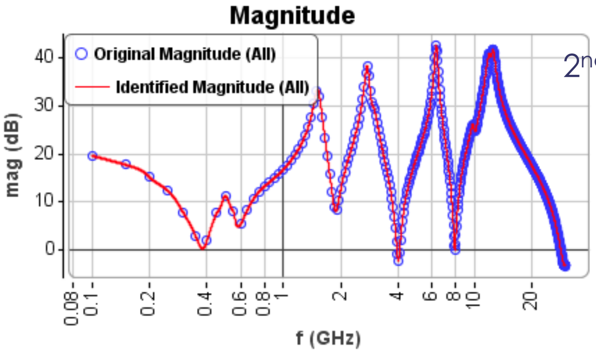
Two STAN probes connected to the gate of transistor, one for each stage

Frequency range from 0.1 to 30 GHz



1st stage



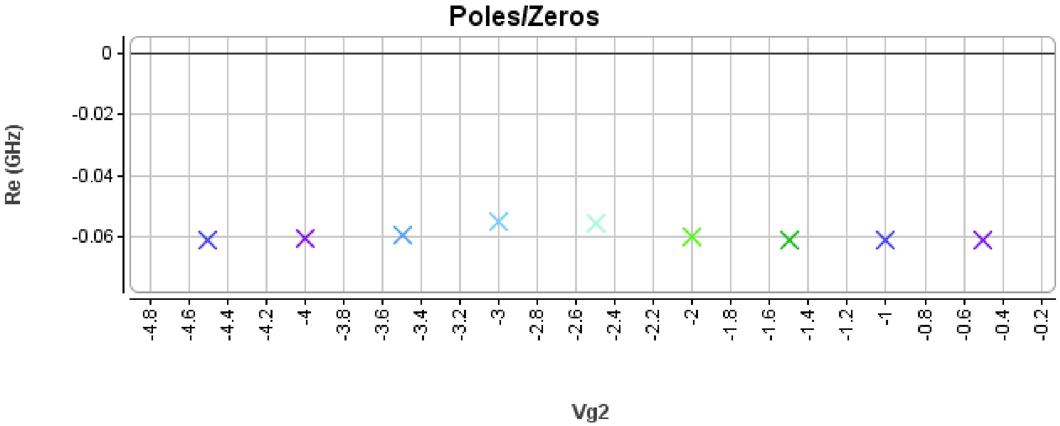


2nd stage

Perform identification in several sub-bandwidths

DC stability analysis

Perform parametric analyses (sweeping parameters such as gate voltage) and focus around the frequencies for which there is a resonance

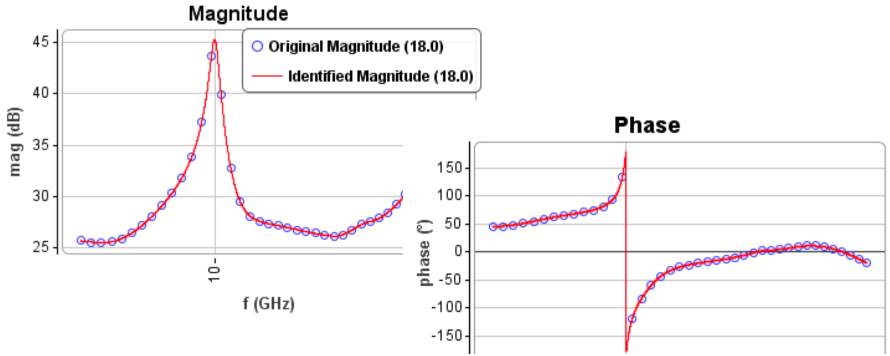


Evolution of the poles at 1,5 GHz while sweeping the gate bias voltage

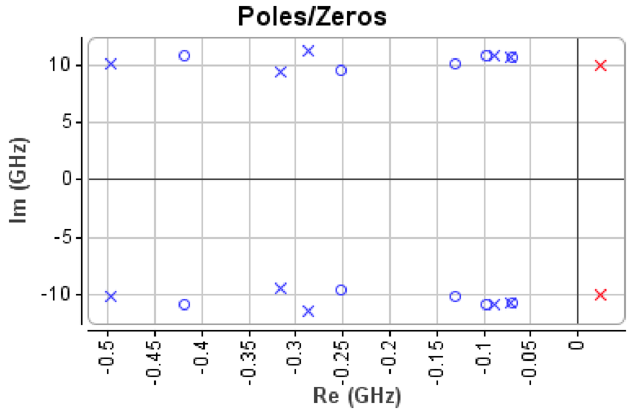
Large-signal stability analysis

STAN probe connected to the gate of a transistor of the **first stage**, f_{in}=10GHz and the input power is swept from 10 to 20dBm, the frequency of the small current probe is swept from 0.1 to 10.1GHz (with avoiding exact overlap with f_{in}=10GHz) → **no oscillation detected**

Same analysis with STAN probe connected to the gate of a transistor of the **second stage → clear instability is detected around** $\boldsymbol{f_{in}}$**=10GHz**



Identification results for F_{in}=10GHz and P_{in}=18dBm



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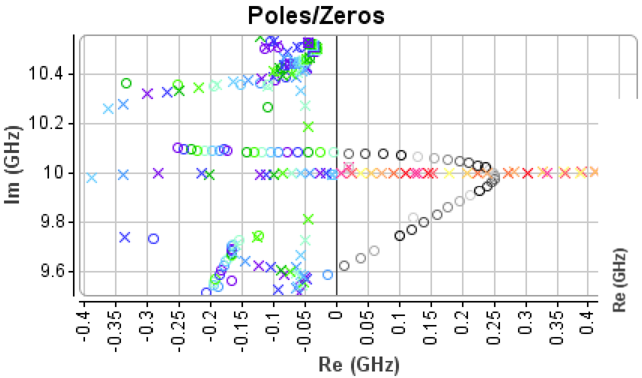
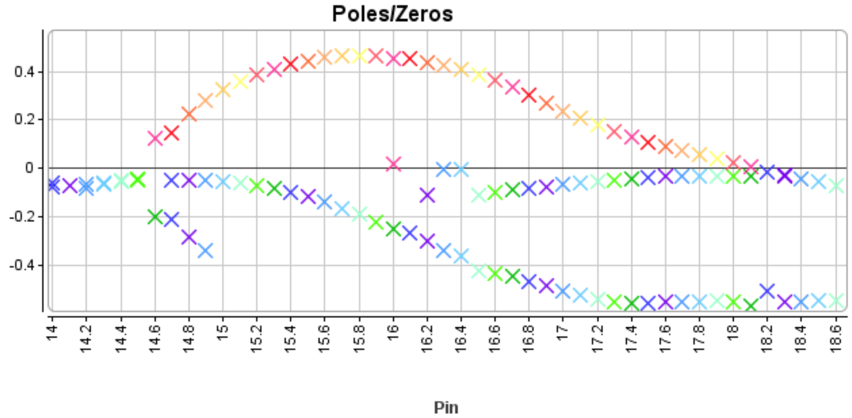
X-band class-E PA

Large-signal stability analysis

Oscillation appears for certain power levels, between ~14 and 17dBm,





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X-band class-E PA

Detection of the oscillation mode

Test of the 4 branches with 4 probes, changing the phase

Even mode (++++): unstable poles are quasi-cancelled, there is not an even mode

Odd mode (+-+-): poles are clear and isolated, observability is high, instability can be [+-+-]

Odd mode (++--): again poles are clear and isolated. Instability can also be [++--]

Odd mode (+--+): poles are quasi-cancelled, poor observability. Instability cannot be [+--+]

Instable dynamics involves an odd mode in which transistors 2 and 3 of the second stage are out-of-phase

Arriving at $P_{in}=14,7dBm$, the signal switches from an even mode to an odd-mode. We suddenly have signal at f_{in} in the transistor 2 that is 180-out of phase with the signal in transistor 3. This means lot of current flowing through the middle stabilization resistor at fin

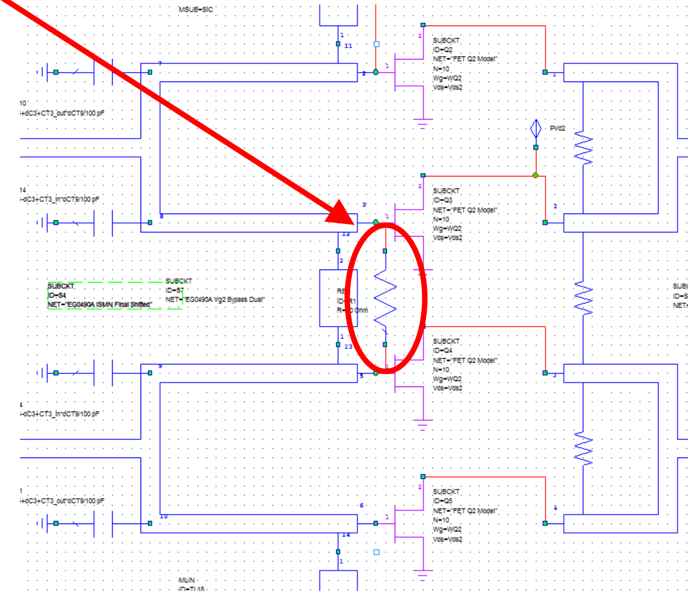
→ Coherent with what was observed in the lab!

Circuit stabilization

The instability involving transistors 2 and 3 of the second stage, a parallel resistance between the gates of these two transistors is added

Value of this inter-branch resistance is swept in order to find one which can guarantee the stability of the PA for all the input range

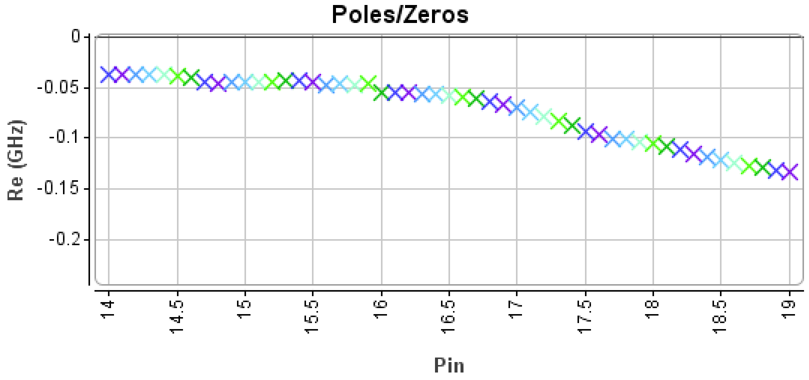
A value between 25 and 30 Ohms seems to be a good choice



X-band class-E PA

Circuit stabilization

The instability involving transistors 2 and 3 of the second stage, a parallel resistance between the gates of these two transistors is added



Evolution of the poles around 10GHz versus P_{in} with inter-branch stabilization resistance of 30 Ohms

2nd run gave stable PA → Now a commercial product

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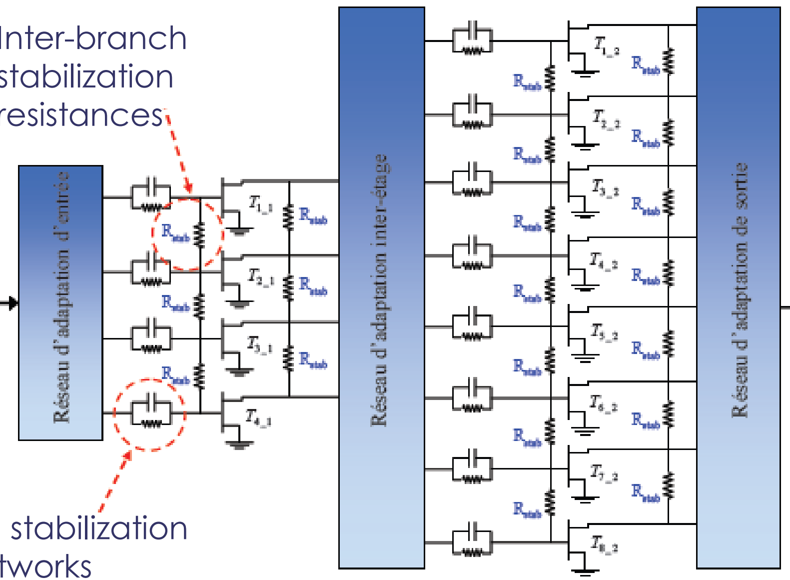
Example: Ku-Band MMIC PA for active space antenna

Stable original circuit

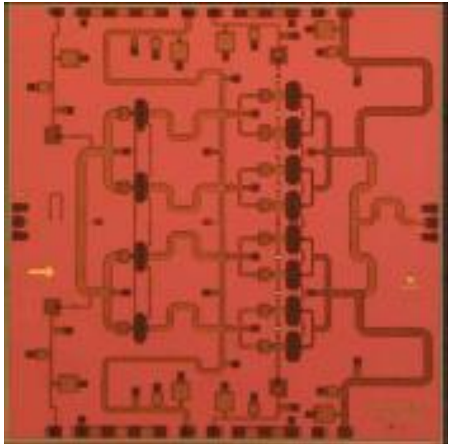
Inter-branch stabilization resistances

RF in



RF out

RC stabilization networks



Natanael Ayllón Rozas "Développement des méthodes de stabilisation pour la conception des circuits hyperfréquences : Application à l'optimisation d'un amplificateur de puissance spatial.", *PhD Thesis*, February 2011.

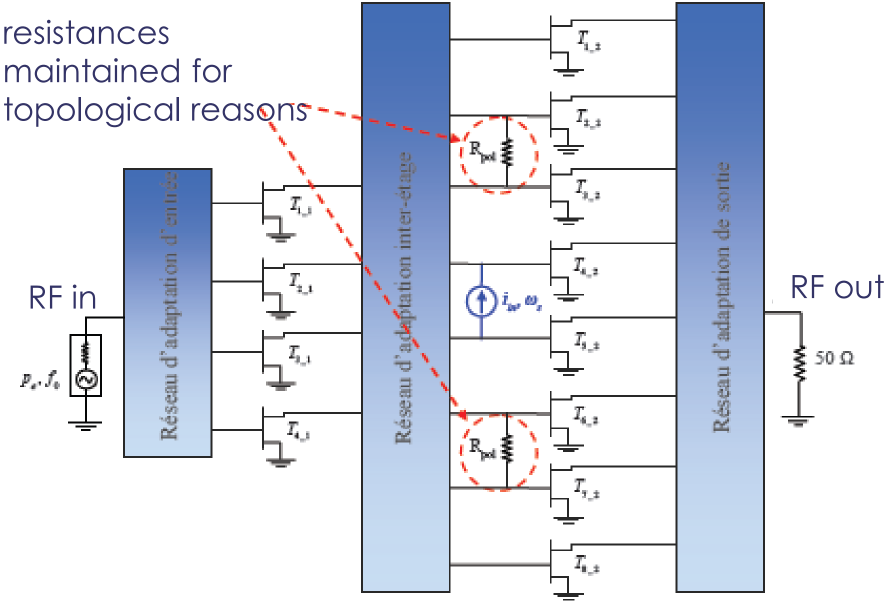
STAN Tool

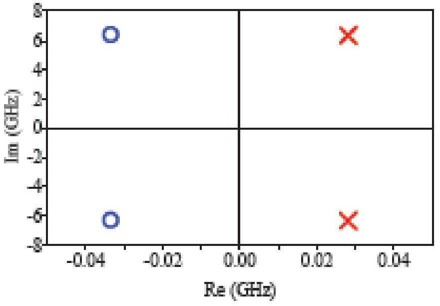
Performances Optimization

Example: Ku-Band MMIC PA for active space antenna

All stabilization networks removed

resistances maintained for topological reasons





Parametric frequency division /2 instability

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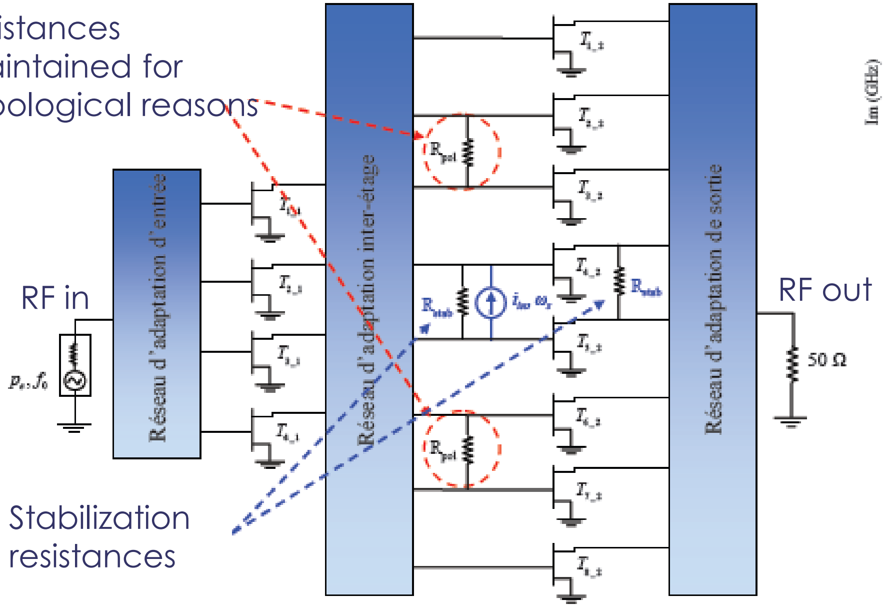
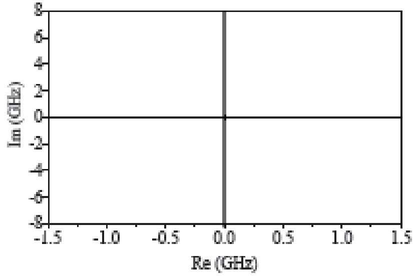
Example: Ku-Band MMIC PA for active space antenna

Optimized version

resistances maintained for topological reasons



Stabilization resistances



No oscillation detected, especially around F0/2

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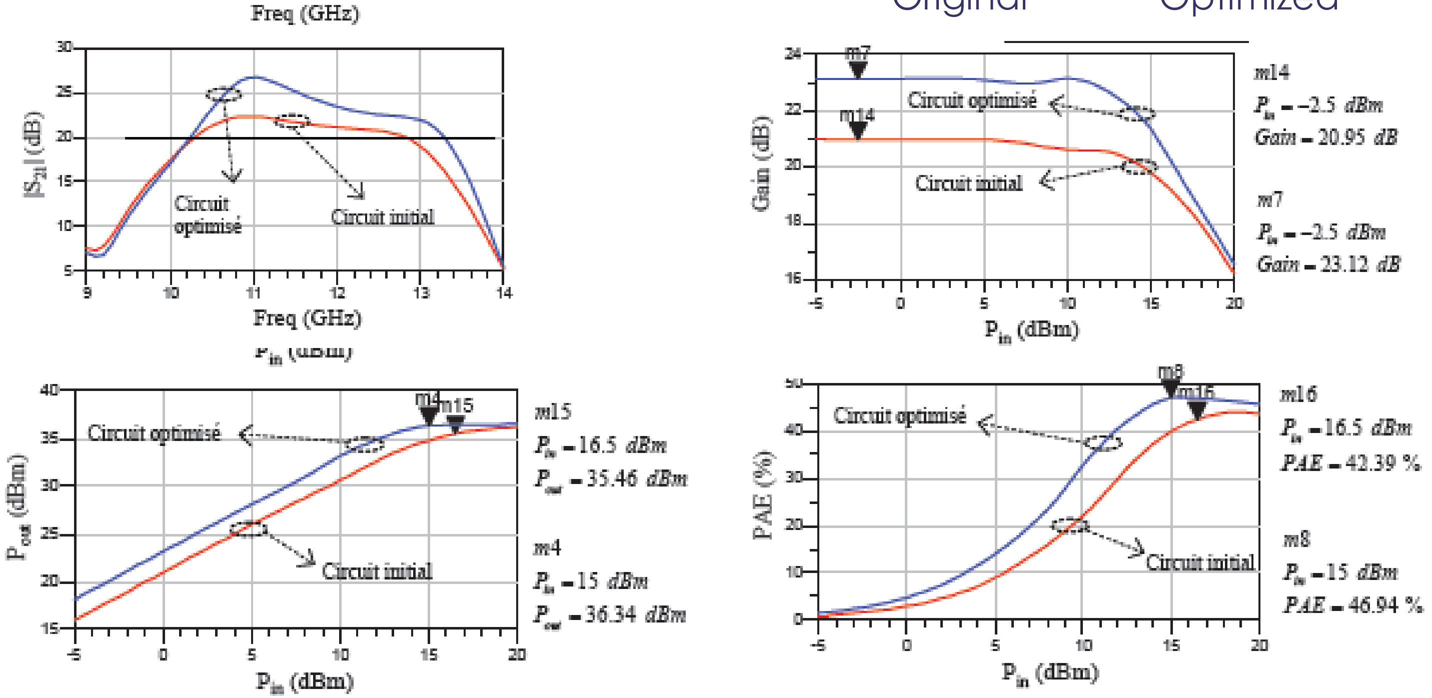
Performances Optimization

Example: Ku-Band MMIC PA for active space antenna

Results comparison

Original Optimized



Thank you

Booth # 328

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